Motivation and Guided Complex Learning of Solar Geometry

Bronne C. Dytoc[1]
bdytoc@kennesaw.edu

Abstract

This paper discusses the integration of motivation and guided complex learning in mastering basic solar-geometry, as taught in the environmental technology course, ARCH 3314, taught in Kennesaw State University's Undergraduate Architecture Program. The rethinking of the topic's instructional strategies responds to the objectives of improved appeal, relevance, and engagement for the technical course while integrating aspects of problem-based learning and scaffolded guidance on learning complex tasks. The problem-based learning map helps in motivating the students' critical learning of solar responsive design, paving a path to a deeper appreciation of passive sustainability, while the drawing and modeling methods are quite instrumental in the guided learning of complex tasks.

Students enrolled in the course have initial introductions regarding the earth's tilted relationship to the sun, and its seasonal patterns across different latitudes. The heliodon is very instrumental in transferring the reference from a celestial to a terra-centric point of view, smoothly moving to sunpath diagram exercises and applying raytracing onto orthographic drawings. The next phase in the learning is the generation of shading masks from overhangs, fins, louvers, and gridded shade solutions. Orthographic analyses of shading devices generate corresponding masks with full and half shade performance, based on how a sun could "see" it. The shading mask can now be properly oriented and overlaid onto a site's sunpath diagram that is rendered with the locale's average seasonal temperatures. The juxtaposition of these two layers then allows for a relatively comprehensive evaluation of the solar shading device's performance throughout the whole year.

Having scaffolded the students' learning to appreciate and interpret the layered graphic information of sunpath, seasonal temperatures, and shading masks, they apply these skills in designing and testing of shading devices for their Design II Studio building's west façade, which performs poorly in terms of solar response. Having actual experience of these spaces contributes to their project's sense of real-world relevance to their project exercise. Student teams construct and apply their design onto a scaled model of the building. The model itself is set on a Heliodon table that turns and tilts to accurately simulate solar behavior in early and late afternoon, during spring, equinox, and winter. Photographs of the exterior and interior are systematically documented; and all this accumulated information is ultimately laid out in a large poster.

Pedagogically, while these instructional methods have much improved the learning experience over previous years, the student responses to post-course surveys still point to the need of yet more improvement in the design and delivery of the instruction.

Keywords: architecture pedagogy, solar-responsive design, problem-based learning, guided learning for complex tasks, instructional design strategies

I. Introduction - Spotting Learning Gaps and Preferences

Technology courses in Architecture may often experience patterns of disconnection. This attitude may be partially an adversarial relationship with STEM-based (STEM = Science, Technology, Engineering, and Mathematics) topics, complicated with a misalignment of the predominant visual learning profile of architecture students (Mostafa and Mostafa, 2010). In addition, technology courses in architecture may be often taught similarly to conventional science classes, with more focus on technical tasks and less appreciation for rationale.

While Kennesaw State University's Architecture program's environmental technology course on lighting and energy continues to reshape its instruction to integrate sun and daylighting issues, observations of previous class behavior and student learning proofs paint a picture of fair to mediocre levels of motivation and engagement. In terms of student performance, simpler exercises deliver scores in the range of 85-95 percent, a healthy assessment attributable to students working with one another; however, when performance is seen in the form of the final project application or the examination for the topic, the range of performance widens significantly from a low of 55 percent to a high of 98 percent, with an average score of 76 percent. Observations of class behaviour reveal a similar pattern: consistent high-level performers engage the material, attend class sessions, and participate in discussions; those who perform poorly are sometimes absent, and often take part as a "follower" with less enthusiasm and engagement to comprehend the material. Despite the fact that students acknowledge the relevance of solar geometry knowledge in architecture, the relatively disconnected attitudes towards learning the content and its techniques point to disturbing gaps in the learning cycle.

[1]Bronne Dytoc is an assistant professor of Architecture at Kennesaw State University and a former faculty member of the University of the Philippines College of Architecture. He has been teaching since 1993, handling senior and foundation design studios, as well as introductory courses in structures and environmental technology.

I am hypothesizing that such low-motivation attitudes result from the fragmented nature of the exercises and its lack of a unifying thread. Thus, improving the learning environment may possibly be realized through awareness of the topic's relevance and exercises' contributions towards better architectural design thinking. Having shifts of perspective (Black and Duff, 1994) from detail techniques to big-picture contexts, and back, may contribute to a more critical understanding of the topic's role in better sustainable design thinking. Secondly, the design of the instructional sequence and use of selective learning strategies may further improve the topic's appreciation, and consequently add to its relative mastery of knowledge and skills. Design students learn initially by psychomotor and cognitive mimicry; cycles of demonstration-discussion-drills with immediate feedback may aid in affirming relevance while increasing appeal and boosting confidence and satisfaction – these four ingredients forming the major component of the ARCS motivational model (Keller and Deimann, 2012).

II. Instructional Approaches for Visually Skilled Learners

Despite the traditional format's persistent presence in educational practice, the lecture as a prime method of instruction is also one of the least effective; the rise of several current approaches (problem-based learning, authentic learning, active learning, but to name a few) point back to the age-old "learning by doing" truism. For visual learners, the construction of knowledge is also underpinned by "seeing is believing"; the employment of effective visuals combined with narrative delivery works to address cognitive load issues while improving engagement and retention (Strauss, Corrigan, and Hofacker, 2011; Lin and Atkinson, 2011). Additionally, active peer learning (Nicol and Boyle, 2003) has been continuing to gain ground, particularly in physics and retail mathematics. Strategies such as these make for more effective instruction with the appropriate sequencing of graphics and exercises, in contrast to the more disenchanting traditional lectures (Diezmann, et. al. 2009).

Because the knowledge of solar geometry topic is being introduced and learned at a foundational level, instruction of this content and its techniques are intentionally being conducted in manual mode. The idea behind this is that "learning by doing" is more effective when the "doing" is done by the novice-learner as much as possible. This view is supported by an article in the New York Times on the role of handwriting in the learning of language (Konnikova, 2014). A study cited by this article points to the role of manual learning of writing skills in the construction of linkages in different parts of the brain (James and Engelhardt, 2012). Furthermore, Mueller and Oppenheimer (2014) report on how student performance was weaker when notes were taken with laptops, instead of being written manually. In similar fashion, these findings support the strategy of learning solar geometry techniques more critically through manual drawing and graphic modes; students take a more active part in the guided and scaffolded learning of complex tasks (Merriënboer, Kirschner, and Kester, 2003). They construct a richer understanding of shading performance as analyzed against precise solar and climate information.

Finally, organizing the different exercises and techniques in a deliberately guided sequence and framing it in the context of problem-based learning gives a more reliable structure to the learning (Kirschner, Sweller, and Clark, 2006), and a deeper level of relevance and significance to the topic's content. The critical thinking developed in this module through the shifting of perspectives (Black and Duff, 1994) aligns with the cultivation of mindful learning (Langer, 1997), while associating these multi-perspective appreciations helps to establish better retention and operation of the knowledge in memory (Dirksen, 2012).

III. Recognizing Motivation and Encouraging Engagement

Even with the thoughtful use of graphics in the instruction, the intentionality of learning the techniques through manual modes, and the scaffolded, guided sequencing of the content for mindful learning, without motivation, the class experience becomes an uphill struggle for everyone. The ARCS (Appeal, Relevance, Confidence, and Satisfaction) motivation model becomes quite useful in the topic's instructional design (Keller and Deimann, 2012). Appeal is established by presenting solar responsive design as an achievable challenge. The module is mapped out as a learning journey with steps, mini-goals, and outputs, preparing their skills mastery for an end objective of designing and analyzing a shading device for their studio building on campus (Design II).

The actual building as a study platform lends a sense of reality and relevance. Graphical cues in teaching sunpath and shading mask diagrams (Moore, 1985) and analyses of precedents (Olgyay and Olgyay, 1957) contribute much clarity to the learning of the material. In stepped phases, student teams layer shading masks onto sunpath-climate diagrams, generating rich proofs that critically verify or correct their initial design assumptions. Acquiring these skill sets in active class environments through guided instructional procedures of demonstration, discussion, and drills with instructor and peer feedback, serve to construct competence, and with it, confidence as well as satisfaction. Furthermore, testing of their shading designs through actual model simulation allowed for photographic proofs to verify their graphic analyses, while simultaneously strengthening their scientific thinking and realizing their designs' potential for performative aesthetics. These many different strategies all interweave to improve student motivation and encourage learning engagement.

IV. Employing Drawing Skills to Construct Knowledge Comprehension

Spatial orientation ability in architecture students is put to good use in relating sun-earth relationships; working initial exercises with the heliodon (see Figure 1) sets the understanding of sunpath diagrams as flattened, projected translations of polar coordinates, azimuths and altitudes.

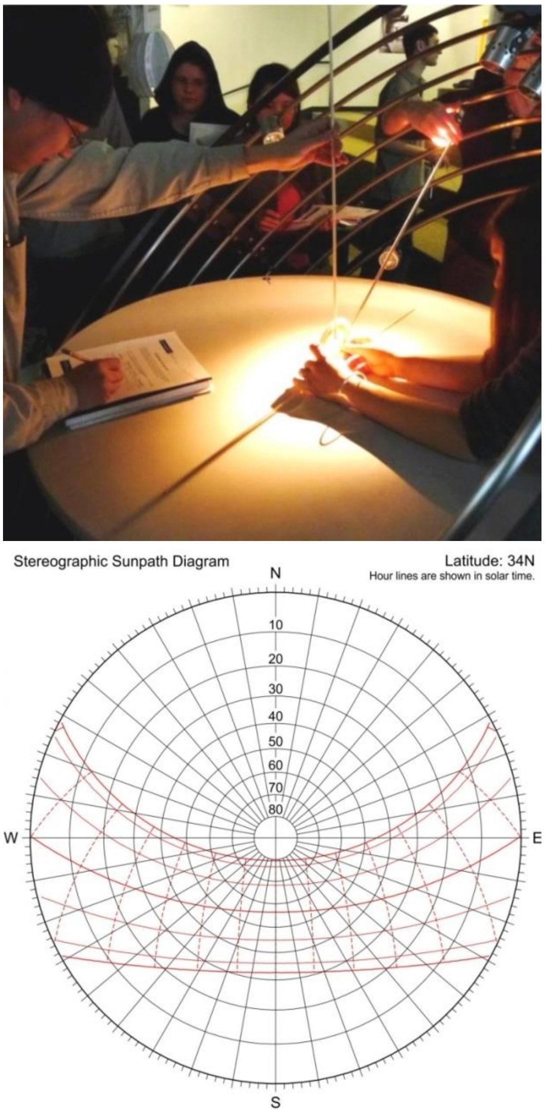

Figure 1. Peer active learning (top) with the heliodon makes very clear how precise and predictable solar geometry translates into the sunpath diagram (bottom).

Source: Retrieved from http://www.jaloxa.eu/resources/daylighting/sunpath.shtml.

To introduce the issue of thermal comfort in a simple yet related manner, a selected local's city (Atlanta) climate profile is mined for temperature data in a typical year; this data is then color-layered as onto winter-spring and summer-fall sunpath diagrams, graphically defining the lag between annual solar symmetry and seasonal temperatures (see Figure 2). These form the two levels of reference information against which a shading design's performance promise is analyzed and evaluated.

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Typical Meteorological Year - Atlanta
(Dry Bulb Temp.) F

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0:01- 1:00	36.68	43.34	53.24	56.48	63.14	69.98	73.58	74.84	68.00	56.66	49.64	42.80
1:01- 2:00	36.14	41.90	51.98	55.40	62.42	68.72	72.50	74.66	67.28	55.76	48.38	41.72
2:01- 3:00	35.42	41.18	51.08	55.22	61.16	67.82	71.60	73.94	66.92	55.04	47.48	40.64
3:01- 4:00	34.70	40.10	50.18	54.32	60.62	67.28	70.88	73.22	66.56	53.96	46.58	39.92
4:01- 5:00	34.16	39.74	49.46	53.24	60.26	66.38	70.52	72.86	66.02	53.42	45.68	39.38
5:01- 6:00	33.80	39.38	48.92	52.52	60.44	66.74	70.34	72.50	66.02	52.88	45.32	39.02
6:01- 7:00	33.44	38.66	48.56	53.42	61.70	68.90	71.60	73.22	66.56	52.34	44.78	38.66
7:01- 8:00	33.44	39.02	49.64	57.92	64.94	72.50	74.84	75.56	69.08	54.68	45.32	38.30
8:01- 9:00	34.70	41.18	51.98	61.34	68.90	76.64	78.26	78.26	72.14	58.46	48.74	41.18
9:01-10:00	37.40	44.24	54.86	64.76	72.32	79.88	80.96	81.50	74.66	61.70	52.70	44.42
10:01-11:00	39.74	47.12	57.92	67.82	74.84	82.58	83.30	83.84	77.00	65.30	56.48	47.48
11:01-12:00	42.08	49.46	60.26	70.52	76.82	84.20	85.10	85.46	78.62	67.10	59.00	50.18
12:01-13:00	43.70	51.80	61.88	71.96	78.26	85.64	86.72	86.54	79.52	68.36	61.16	52.16
13:01-14:00	44.96	53.60	63.50	73.04	77.90	86.54	87.08	87.62	79.34	69.98	63.14	53.96
14:01-15:00	46.04	54.68	64.94	73.58	79.16	86.54	87.80	87.80	79.88	70.52	64.04	54.68
15:01-16:00	46.04	54.68	65.66	73.58	79.16	86.18	87.98	87.98	79.34	70.34	64.04	54.50
16:01-17:00	45.14	54.32	65.30	73.04	78.08	85.64	86.72	86.90	78.62	69.08	62.42	53.06
17:01-18:00	43.70	52.52	64.22	71.06	76.64	84.38	85.64	85.10	76.82	65.84	59.18	50.90
18:01-19:00	42.08	50.90	62.24	68.00	73.94	82.04	82.76	83.12	74.30	63.50	57.02	49.10
19:01-20:00	41.18	49.46	60.62	64.94	71.06	77.90	79.88	80.42	73.04	61.34	55.22	47.84
20:01-21:00	40.10	47.48	58.82	62.60	68.90	75.20	78.08	78.98	71.96	60.08	53.78	46.40
21:01-22:00	39.20	46.22	57.38	60.26	67.28	73.58	77.18	77.72	70.88	58.82	52.34	45.50
22:01-23:00	38.12	45.32	55.58	58.82	65.84	72.32	75.74	76.82	69.80	58.10	51.26	44.60
23:01-24:00	37.58	44.60	54.32	57.92	64.58	71.42	74.84	75.92	68.90	56.84	50.00	44.24

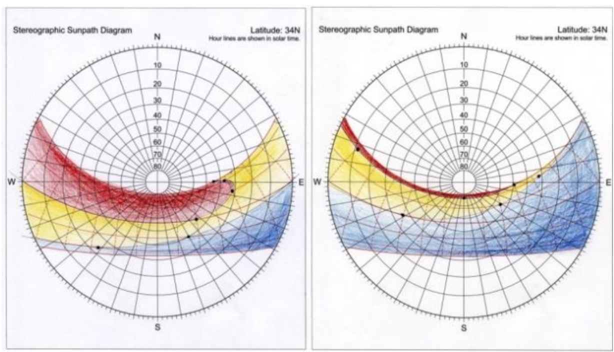

Figure 2. Dry bulb temperature data for a typical year in Atlanta (see top table) are color-coded for cool (blue), comfortable (yellow-white), and warm (red) periods. This data is then translated in similar fashion onto the sunpath diagrams (bottom). The left sunpath diagram shows temperature colors for the period from June through September into December, while the right sunpath shows temperature colors from December through March into June (diagrams by S. Cook).

Source: TMY data retrieved from http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/.

The next and difficult task to learn is the generation of the shading mask. The radial projection of orthogonal lines onto a domical surface to make the shading mask template may be simpler to learn (see Figure 3); however, translating overhangs, fins, and grids into shading masks requires more focus and training. Students reach this necessary level of mastery by envisioning shading coverage from a solar point of view (Can direct sunlight enter through a shading device?). It is in this area that their spatial reasoning is often challenged, and, with practice, eventually sharpened to the requisite degree of cognitive operational precision, enough to generate shading masks of full and half coverage (see Figure 4).

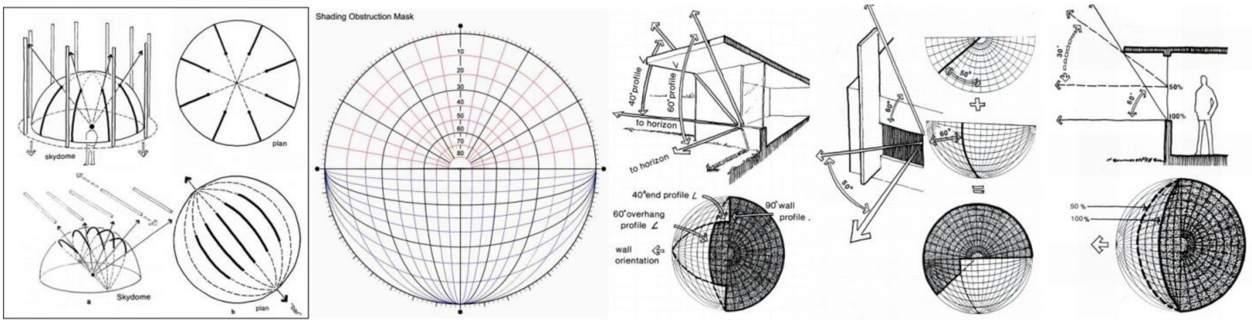

Figure 3. Well-crafted graphics are quite instrumental in the instruction of shading masks. Two cognitive challenges are tackled in learning this particular topic: 1) the translation from Cartesian to polar coordinate systems, and 2) the shifting of visualization skills from a person's perspective to that of the sun's view into a window.
Source: Moore, Fuller. Concepts and Practice of Architectural Daylighting (1985).

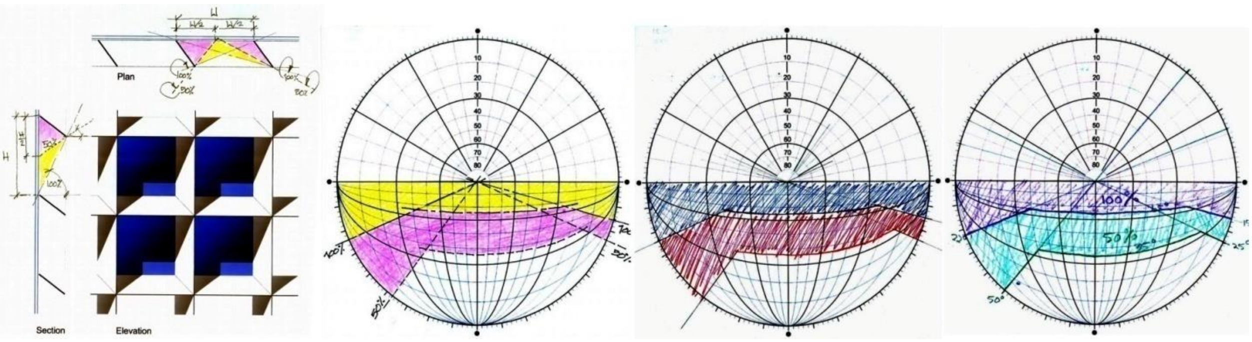

Figure 4. Once students are able to shift to a solar perspective, determining the angles for shading coverage from both plan and section (left) becomes a task that is better appreciated as a necessary and clear step towards translating the design into its shading mask profile (exercise key, middle, and 2 samples of precise student work, right).

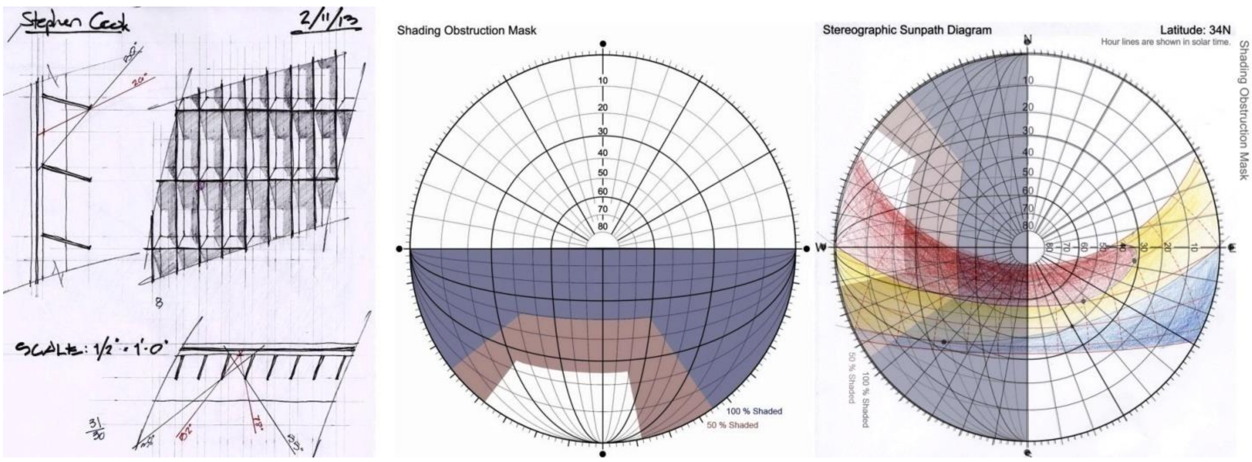

Figure 5. The distinct tasks finally converge: determining a design's shading angles (left), translating these angles to generate the shading mask (middle), and orienting the mask on top of the sunpath+climate diagram (facing west, during summer-fall period, in this particular case) (right). These layered graphics, scaled appropriately to each other, clarify the complexity of information, and confirm the shading design's performance for a particular orientation, during particular times of day, and particular months of the year (graphics by S. Cook).

All of these skills and their outputs come together at last when an accurately drawn shading mask is properly oriented on top of a site's combined sunpath and climate diagram. Now the particular shading device can be analyzed to see how well it is able to obstruct direct sun during summer, and allow desirable solar penetration during winter months (see Figure 5).

V. Witnessing a Design's Performance Fuels Learning Motivation

Up to this point, the skills and knowledge being learned still remain in the technical and theoretical realm. Without a larger goal of creative and actual application, the motivation for learning and retention of this topic's

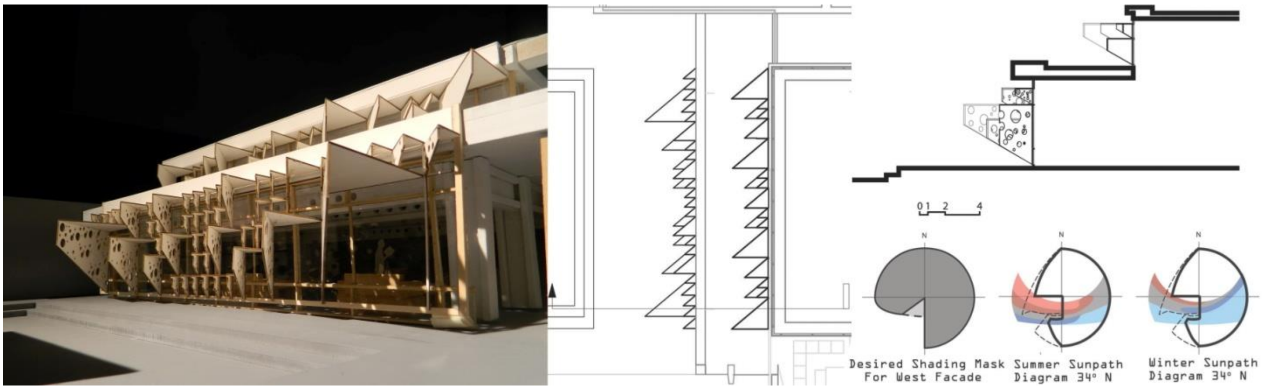

Figure 6. This proposal's unique motif of "Swiss cheese wedges" (by B. Moges and C. Ayers) are so angled in a southwesterly fashion, to achieve the prime objective of blocking out the summer sun while allowing solar access during winter. Being a static design proposal, the student team was aware of their design's solid performance during summer months, as well as its limited solar access during winter months.

content tend to be fair to poor, with bookish knowledge transferring weakly into subsequent studio tasks. Recognizing this drive in architecture students to design, and integrating it to become the topic's "end game" allows the various learned skills to be applied in responsive and performative design application. Recognizing the ARCS motivational model in play, confidence and satisfaction from earlier tasks are important. Developed competence and foresight of success help fuel the appeal and relevance of the larger objective ahead: designing a shading response for the Design II building's west façade.

Using this actual building on campus makes the design challenge more "real"; simultaneously, the experience of the design studios' unwanted solar penetration remain relatively fresh in students' memory. After student teams have documented the poor response of the west facing façades, they generate initial ideas, analyze their potential merit, and refine their design proposal. Figure 6 shows an excellent design example, where the refinement of the shading device was influenced by the temperature profiles rendered on their site's sunpath diagram.

Building their design onto a scaled model of the Design II building's west face allowed for empirical testing. By fastening the design model to a heliodon table, positioning the tilt and turn via the guidance of a roof sundial, and using a powerful light source to act as the sun, each design was assessed and photographed. Furthermore, they were able to appreciate their shading proposal's architectural aesthetic. Each team then compiled their generated data into a final project poster. A selection of afternoon pictures (before and after treatment) are shown in Figure 7.

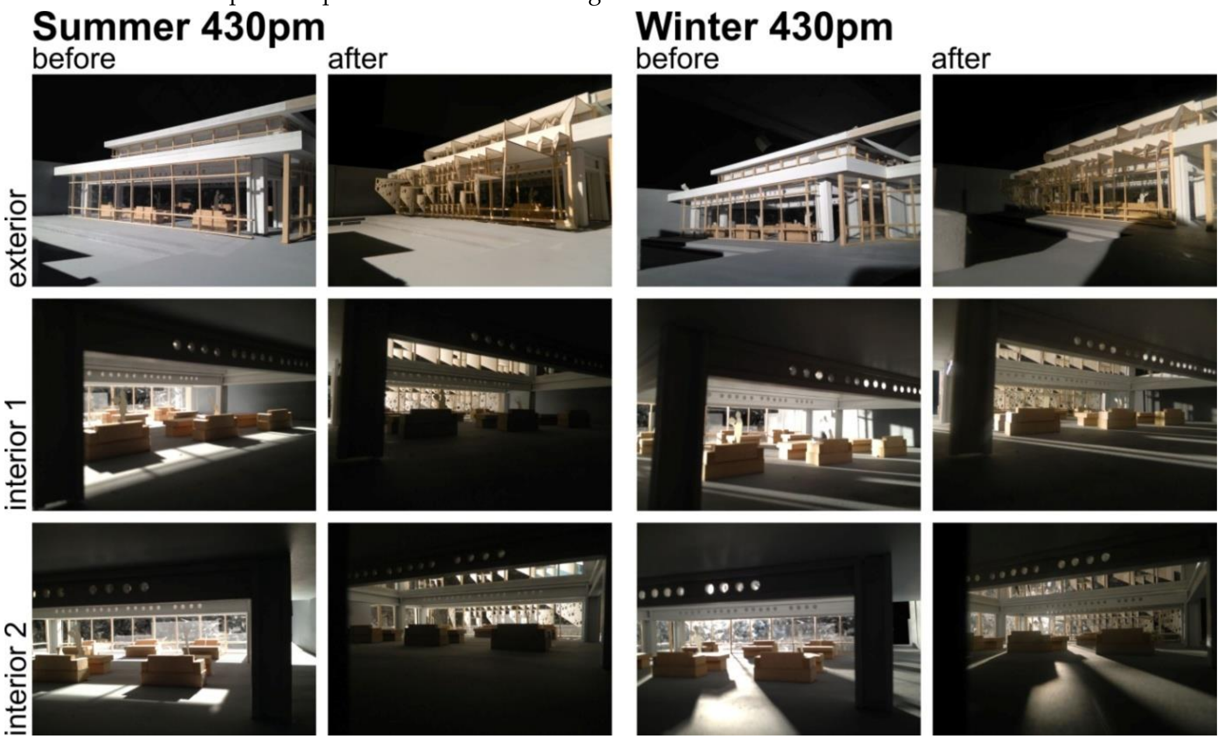

Figure 7. This matrix shows "before and after" photographs of the shading design (by B. Moges and C. Ayers), simulated at 430 pm, solar time, during the summer solstice, Jun 21, and the winter solstice, Dec 21. Note solar exclusion in summer and solar access in winter. The top row shows an exterior view; the next two rows display two interior views.

VI. Reflections on Instruction

In a preliminary post-topic survey documenting learner perceptions and attitudes, students opined, as anticipated, that the topic was relevant, though how it was presented (appeal) could improve. They were fairly positive about instructional clarity, mildly agreeing that precision and critical thinking were encultured. They were mild-neutral about their learning and master, and they expressed fair levels of intent to apply these techniques in their future design work. This feedback, while markedly improved from previous years' classes, is still far from the desired ideal of energized student motivation and engagement.

Teaching a technology course for architecture students is always a challenge, and this course with this particular topic is no exception. Though it may be easy to realize that the natural tendency is to teach the way we are taught (Beegle and Coffee, 1991, Smeaton and Waters, 2013), the prevalence of lectures as the prime format must evolve continuously towards active and learner-centered platforms (McCombs and Miller, 2007, Smart, Witt, and Scott, 2012). Nevertheless, I can state clearly that delivery of the instruction is gradually improving. With the integration of the instructional approaches : 1) highlighting graphical skills, 2) mapping the learning of skills towards a larger relevant goal, 3) developing mastery of the content and skills through manual drawing and modelling, and 4) sequencing the complex learning tasks in a guided manner, the increase in overall motivation and engagement for the class is noticeable.

While I personally would have wished for more positive opinions, I must also recognize that these responses may be influenced by several things. One factor may be the all-too-familiar struggle to balance and carry their academic load along with demanding studio work; another may be the limited time with which to hone their skills to achieve a fuller comprehension of the subject and deeper appreciation for its significance. An awareness of their relatively developing skill level is not at all bad; it may, however, also explain the neutral opinion regarding their mastery, and consequently, their confidence, which affects overall motivation.

I am realizing that mapping out the learning plan more clearly can help elevate engagement levels and the effort to finish well. While instruction through demonstration and discussion may improve clarity in understanding, proper time must still be allocated for exercises and feedback. Finally, in hopes of enhanced motivation, the firmer construction of the topic's relevance to architectural design may be achieved by having students undertake contemporary case-study analyses. While the recipe of instruction methods and the learning environment continues to develop, it has become clearer that employing drawing and modelling abilities, as well as energizing students through creative design application, are key ingredients in the learner-centered environment of the architectural technology class.

References

Beegle, J.J., & Coffee, D.D. (1991). "*Accounting Instructors' Perceptions of How They Teach versus How they were Taught*". Journal Of Education For Business 67, no. 2: 90-94.

Black, Gary and Duff, Stephen (1994). "*A Model for Teaching Structures: Finite Element Analysis in Architectural Education*". Journal of Architectural Education 48, no. 1: 38-55.

Diezmann, Carmel, Lowrie, Tom, Sugars, Lindy, & Logan, Tracy (2009). "*Students' Sensemaking with Graphics*". Australian Primary Mathematics Classroom14, no. 1: 16-20.

Dirksen, Julie (2012). Design for How People Learn. Berkeley, CA: New Riders.

James, Karin and Engelhardt, Laura (2012). "*The Effects of Handwriting Experience on Functional Brain Development in Pre-literate Children*". Trends in Neuroscience and Education 1, no. 1: 32-42. doi:10.1016/j.tine.2012.08.001.

Keller, John, and Deimann, Markus (2012). "*Motivation, Volition, and Performance*". In Trends and Issues in Instructional Design and Technology, 3rd edition, edited by Robert A. Reiser and John V. Dempsey, 84-95. Boston, MA: Pearson.

Kirschner, Paul A., Sweller, John, & Clark, Richard. E (2006). "*Why Minimal Guidance during Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based,Experiential, and Inquiry-Based Teaching*". Educational Psychologist 41, no. 2: 75-86.

Konnikova, Maria (June 2, 2014). "*What's Lost as Handwriting Fades*". New York Times. http://www.nytimes.com/2014/06/03/science/whats-lost-as-handwriting-fades.html?_r=0.

Langer, Ellen (1997). *The Power of Mindful Learning*. Boston, MA: Addison-Wesley.

Lin, Lijia& Atkinson, Robert K. (2011). "*Using Animations and Visual Cueing to Support Learning of Scientific Concepts and Processes*". Computers & Education56:650-658. doi:10.1016/j.compedu.2010.10.007.

McCombs, Barbara. L. & Miller, Lynda (2007). *Learner-centered Classroom Practices and Assessments: Maximizing Student Motivation, Learning, and Achievement.* CA: Corwin Press.

Merriënboer, Jeroen J.G., Kirschner, Paul, and Kester, Liesbeth (2003). "*Taking the Load off a Learner's Mind: Instructional Design for Complex Learning*". Educational Psychologist, 38, no. 1: 5-13.

Moore, Fuller (1985). *Concepts and Practice of Architectural Daylighting*. New York: Van Nostrand Reinhold.

Mostafa, Magda and Mostafa, Hoda (2010). "*How Do Architects Think? Learning Styles and Architectural Education*". Archnet-IJAR, International Journal of Architectural Research4, nos. 2/3: 310-317.

Mueller, Pam and Oppenheimer, Daniel (June, 2014). "*The Pen is Mightier than the Keyboard: Advantages of Longhand over Laptop Note Taking*". Psychological Science25, no. 6: 1159-1168. doi:10.1177/0956797614524581.

Nicol, David and Boyle, James T. (2003). "*Peer Instruction versus Class-wide Discussion in Large Classes: A Comparison of Two Interaction Methods in the Wired Classroom*". Studies in Higher Education 28, no. 4: 457-473.

Olgyay, Aladar and Victor Olgyay (1957). *Solar Control and Shading Devices*. Princeton: Princeton University Press.

Smart, Karl L., Witt, Christine, & Scott, James P. (2012). "*Toward Learner-Centered Teaching: An Inductive Approach*". Business Communication Quarterly75, no. 4: 392-403. doi:10.1177/1080569912459752.

Smeaton, P. S., and Waters, F. H. (2013). "*What Happens When First Year Teachers Close Their Classroom Doors? An Investigation into the Instructional Practices of Beginning Teachers*". American Secondary Education41, no. 2: 71-93.

Strauss, J. F., Corrigan, H., and Hofacker, C. (2011). "*Optimizing Student Learning: Examining the Use of Presentation Slides.*"Marketing Education Review21, no. 2: 151-162. doi:10.2753/MER1052-8008210205.